Video Game Pioneers: The New Animators

The engineers responsible for the development of today's video game systems and cartridges have much in common with Walt Disney and his early animators. Disney and animators such as Ub Iwerks (Mickey Mouse), and Jack Hannah and Fred Spencer (Donald Duck) succeeded because they understood how to merge two different fields of endeavor (cinematography and cartoon art).

Video game system designers had to master two different disciplines, too: solid-state electronics and software. Atari, Odyssey and Mattel designers took up the challenge, and as a result, home electronics entertainment has entered a new era.

Pioneering in video game systems is continuing. Atari plans to bring out a more sophisticated version of its present game console later this year; Mattel and Odyssey are developing voice-and-sound modules to augment the capabilities of existing game units. New game systems are also expected from Coleco and Astrovision during the fall.

Because of the efforts of two electronics engineers, Ralph Baer and Nolan Bushnell, the video game industry exists; the work of both is covered in the following pages. The story of Ed Averett, a former Intel engineer, who became the designer of most of Odyssey's cartridges, is also presented. Averett, with help from his wife Linda, a Hewlett-Packard software systems manager, needed only three months to develop, demonstrate, and sell his first cartridge design.

Is there room for more Ed Averetts in the TV game industry? The statistics make it seem so.

Current projections call for the sale of 5.5 million game consoles in 1982 at a retail value of approximately $1 billion. According to David M. Arganbright, vice-president and general manager of Odyssey, the typical owner buys an average of six cartridges within one year after the purchase of a game and ten per year in the following years. If Arganbright is correct, each 1000 game consoles sold this year will generate nearly $1 million in cartridge sales by 1986.

Even if Arganbright's projections are optimistic, there appears to be lots of room for more Ed Averetts. The work can be profitable, too. Averett will earn about $2 million in royalties from cartridge sales in 1982.

— *Jerry Eimbinder*

Atari has converted several of its coin-operated arcade games, including Breakout, into home video cartridge games. When Mattel enters the coin-operated game market later this year it may reverse the process and build arcade games based on successful cartridges.

Bushnell Founded Atari on Innovation and Perseverance; But, For Years, Stability Eluded Him

"As soon as I saw what the trouble was, I knew I had a winner — the coin box was stuffed to capacity."
— Nolan Bushnell, Founder of Atari

Every story has a beginning. Except for the video game. It has two beginnings. Or maybe more.

In a sense, the beginning took place at the Massachusetts Institute of Technology in 1962 when a graduate student named Steve Russell wrote a program for playing a game called Spacewar on a Digital Equipment Corp. PDP-1. There were two other beginnings, by Ralph Baer and Nolan Bushnell, that were directly responsible for the birth and growth of the video game industry.

In order to play Russell's Spacewar, engineers and other employees of companies possessing computers had to obtain computer time one way or another. Some returned to the plant late at night and guided rocket ships across computer displays until nearly dawn. Others found ways to use their company's computers during prime working time.

The Spacewar program was passed from college to college during the 1960s. Two of the students who learned the game on the college campus were Nolan Bushnell at the University of Utah and Bill Pitts at Stanford University's Artificial Intelligence Center.

Threat to Pinball

Bushnell had worked in the penny arcade of an amusement park in Salt Lake City during summer vacations from college, and he envisioned an arcade version of Spacewar as the first threat to pinball in 40 years. Pitts, too, had a similar belief. Both, unaware of the other's plans, set out to develop a coin-operated arcade version of Spacewar in 1971.

A bad business slump hit the electronics industry in early 1971 and the prices of TTL integrated circuits plummeted. Suddenly, it became economically feasible to build an arch-rival to pinball. Bushnell quit his job at Amperex Corporation and joined Nutting Associates in Mountain View, where he finished the design. His new employer bought all rights to the design, named the game Computer Space and displayed Bushnell's machine, priced at $1850, at a 1971 trade show. Interest was sufficient to encourage production of the game and deliveries began in early 1972.

Computer Space used a raster monitor from a 19-inch G.E. television set and approximately 185 integrated circuits, mostly TTL devices. Orders for the game were disappointing; many distributors feared that it was too complicated for the average arcade customer to comprehend. Financially, Computer Space was a failure. But its development had taught Bushnell all he needed to know to start his next project.

How Atari Was Named

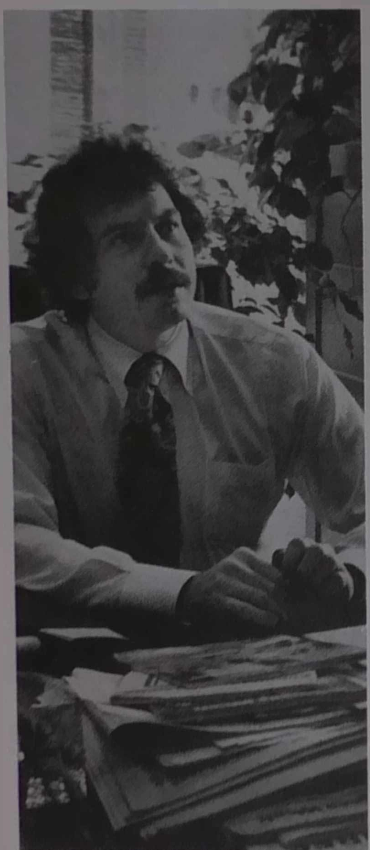
Bushnell and another engineer left Nutting Associates and started Atari. Each contributed $500, which even in 1972, wan't much of a bankroll for founding a company. The name Atari was borrowed from a Japanese game called Go in which one player defeats the other by rendering his playing piece immobile.

Bushnell says that he fought off poverty as a daily routine. Weary of operating on a nearly nonexistant budget, Bushnell packed up a prototype for his first Atari product and brought it to Bally Manufacturing, a Chicago-based pinball-machine manufacturer. Bally wasn't interested and Bushnell's hopes of securing enough cash to start production were dashed.

The new machine still needed to

be field tested and Bushnell found a friendly Sunnyvale tavern owner willing to install it in a corner of his bar. The next day, a five-foot-high machine with a hooded display (to shade the screen) was rolled into Andy Capp's; above the display, four large letters had been painted: PONG. History was about to be made.

Only two days later, Bushnell received a phone call. The machine had stopped working. Expecting to find a problem in the TTL circuitry, Bushnell returned, armed with tools and spare TTL parts. Curious, however, to see if the machine had earned some money before shutting down, he opened the coin box.



Nolan Bushnell, founder of Atari, received $15 million when the game company was purchased by Warner Communications in 1976. Bushnell now heads a fast-food restaurant/theater chain.

"As soon as I saw what the trouble was, I knew I had a winner," recalls Bushnell. "The coinbox was stuffed to capacity."

The income from the Pong machine at Andy Capp's wasn't enough to keep Atari in business but it was more than adequate to convince several pinball-machine distributors to advance the money Atari needed to start production.

Meanwhile, Pitts completed a prototype unit in 1971 and followed with an improved version called Galaxy Game a year later. He placed it in the Tressider Union Coffeehouse at Stanford, a few miles away from Andy Capp's, where unbeknownst to Pitts, Bushnell's Pong was under evaluation. Pitts' game, employing a Digital Equipment Corp. PDD-11, required extensive instruction to master. More players were discouraged than challenged. The machine still stands there today. No more have ever been built.

Their Time Hadn't Come

Ironically, both Computer Space and Galaxy Game were too far ahead of their time. Had they arrived six or seven years later, they would probably have caught on. Although Bushnell fared better than Pitts, the following years weren't easy for Atari. Every time the company seemed to be on the verge of success, a new crisis arose or a new money-making scheme backfired. Notable disasters included an ill-fated atempt to run a parallel operation in Japan and heavy losses from Atari-owned arcades in Hawaii.

But, in 1975, after Atari converted Pong into a home video game, it found a department-store giant was ready to buy every unit it could manufacturer. In a deal that provided Atari with immediate financial assistance, Sears and Roebuck committed to buy 100,000 of the simulated table-tennis games.

Atari was now closing in on Magnavox, which, after selling nearly 100,000 Odyssey paddle games in 1972, had progressed slowly. The original model of Odyessey was expensive to produce and contributed little profit to Magnavox. The unit contained 305 discrete parts in its master control console and hand controls. Overlays were placed on television screens to simulate playing fields. The Odyssey package also included dice, play money, card decks and game boards.

The sluggishness in sales encountered by Magnavox discouraged neither Atari nor Sears and Roebuck. The failure of Odyssey to register better sales during the years after its introduction were attributed to several factors including too many auxiliary components, inadequate promotion, and the widespread belief, caused by its own advertising, that Odyssey could only be used with Magnavox television sets.

Magnavox was also beset with other problems during the period following the introduction of Odyssey. It had delayed in converting its television line to solid-state devices when competitors began moving in this direction. In its rush to catch up, it experienced serious conversion delays and engineering problems. Its consumer electronics operation, which had recorded a $22 million profit in 1972, dropped to a $5.8 million loss in 1973, and then plunged to a $42.1 million loss in 1974. It remained in the red in 1975 with a $10.3 million deficit. Despite its problems, Magnavox seemed determined to support the Odyssey program.

The competition in video games was stiffening. Magnavox, in a redesign had cut the number of parts in Odyssey to 200, and was working on a design that would further reduce the parts count to 75. In addition, new competitors were entering the marketplace. The rush for the 1975 Christmas season business was on.

One of the new competitors was a company called First Dimension Corp., founded in mid-1975, in Nashville by Norvell L. Olive. First Dimension manufactured 7000 games in time to ship for the 1975 holiday season and, in preparation for mass volume of its $129 game during 1966, it purchased $1.5 million in TTL integrated circuits and other electronic parts.

The Six-In-One Chip

But in early 1976, General Instrument introduced the AY3-8500, a video game chip containing nearly all the circuitry required for four paddle games and two rifle games. The chip was priced in the $5 to $6 range, depending on the size of the order. It offered manufacturers the capability to sell video game systems for $60 to $75 instead of $125 or more.

For companies like First Dimension, sitting on large inventories of TTL parts, the news was disastrous. However, for companies not in the electronic game business at the time, it was an open invitation to jump in.

By mid-1976, at least 70 companies were in the home video game business. Once again, Atari began looking for growth capital.

Along came acquisition-minded Warner Communications. Atari was purchased for $28 million, about $15 million of which went to Bushnell. In addition, during the following three years, Warner invested more than $100 million to stabilize and expand Atari.

Bushnell and the new owners soon disagreed on both selling strategies and basic management of the company. He stayed on as chairman of Atari until 1978, when he purchased Pizza Time Theatre, a restaurant/theatre business from Warner for half a million dollars. Warner had inherited Pizza Time Theatre when it bought Atari and had exhibited little interest in the concept during Bushnell's time in office. Only one restaurant, located in a San Jose, CA shopping center, was in business at the time of the sale.

Animated Figures

The restaurant included a separate arcade-game room, stocked with Atari coin-operated machines, but its feature attraction was a show put on by animated robots. Completely microprocessor-controlled, a new two-minute show started every six minutes.

The star of the show was Chuck E. Cheese, a huge rat; Chuck opened with a few jokes and went on to introduce the other members of the cast. It took three hours of programming to set up one minute of character action. Instructions were fed to the figure by the microprocessor at the rate of 450 per second.

Bushnell set up a franchise program starting at $20,000. The set of characters, with training in servicing and programming included, cost an additional $40,000. By early 1980, eight restaurants were in operation. A year later, the number reached 50, and in late 1981, it passed 100.

The company went public at $15 a share. In April, 1982, the price reached $27.50 per share; for Bushnell this represented a gain of $60 million, four times the money he received when he sold Atari to Warner. Not bad for an electronics engineer, 39 years old.

Atari hasn't done badly, either, since the departure of Bushnell. According to *Time Magazine*, in its April 26, 1982 issue, San Francisco securities analyst Ted James projects cartridge and game console sales of $1.3 billion in 1982 for Atari and an additional $400 million in coin-operated arcade game sales. This represents a revenue for Warner that is nearly six times that of its record business, five times the income it receives from films, and about 47 times the return from its Academy-Award winning movie *Chariots of Fire*. □

ATARI'S PONG

Unlike Computer Space, a complicated aerial space dual between a spaceship and a flying saucer, Pong was easy to understand and play. A dashed vertical line at the center of the screen represented the net. Each player turned a knob to move his paddle up or down to hit the ball in the direction of the net. If a player failed to return the ball toward the net, his opponent received a point. Each player's score was continuously displayed in large numbers at the top of the screen.

Original coin-operated Pong machine developed by Atari. Al Alcorn (left) assisted Bushnell in the game's design. A home video version was developed in 1975.

The Birth of the Video Game: The Secret Was "Ball" Control

"I had a strong feeling that I had a tiger by the tail."
— Ralph Baer, Video Game Pioneer

In "The Graduate," a movie produced in the mid 1960's a well-meaning party-goer shared his one-word secret of success with new graduate Dustin Hoffman: "Plastics." If he were still giving out free advice today, his message might well be: "Software."

In the case of Odyssey, two engineers, working almost in different eras, parlayed engineering design capability with knowledge of software to become millionaires. One was Ralph Baer who, in 1967, designed the first video paddle game; the other was Ed Averett who, ten years later, launched a game design career by developing a chase-through-maze game.

Curiously, both obtained their game design skills while following other careers. Baer picked up the background knowledge needed to propel a spot back and forth on the screen while designing a never-marketed TV set for Loral Electronics in the 1950's. Averett became intimately familiar with Intel's 8048 microprocessor because he happened to be selling it; one of his customers was Magnavox and the application was its new video game system, Odyssey 2.

In 1966, Baer, manager of the equipment design division of Sanders Associates, Manchester, NH, at the time, wanted to mount a video game study project. He discovered that there wasn't a single TV raster-scan related project being conducted at Sanders Associates and few engineers with knowledge of TV.

Breadboard Proved Feasibility

"I decided to build my own breadboard and check out my ideas for generating player spots and moving them around a broadcast TV receiver screen under manual control," remembers Baer. Working after hours, Baer built a couple of symbol generators and soon had two spots chasing each other around the screen of a black-and-white TV set. "I had a very strong feeling that I had a tiger by the tail," Baer adds.

At Baer's request, Sanders Associates authorized development of a video game system. Engineers Bill Harrison and Bill Rusch were assigned to the program and, by early 1967, a multiple-player hockey game had been developed in which the puck moved at a velocity proportional to how hard it was hit; it also moved at the same angle at which it was hit. A player could skate with the puck, hand it off to a teammate, or shoot. The puck bounced off all four walls, and an adjustment changed the condition of the ice from fast to sloppy (to give beginners a better chance). The game was played against a background of blue ice.

The color signal generation was obtained very simply. The parts used were one NPN 6.5¢ transistor, two 2¢ diodes, a few resistors and capacitors, a 3.58-MHz chroma crystal, and a 15¢ oscillator coil. With these parts, they built a chroma oscillator and through the use of a center-tapped secondary on the tank coil, they obtained two 3.58-MHz signals 180° out of phase with each other. Taking an output from one side of this secondary and gating it into the video signal with horizontal sync pulses produced an adequate approximation to a color burst reference signal. An RC phase shift network was connected across the secondary's outer terminals; the resistor was a potentiometer so that the phase at the junction of the resistor and capacitor could be varied nearly 0 to 180° with respect to the color burst reference phase. The horizontal sync was used to gate out the new phase signal through the second 2¢ diode into the video signal and background color was produced.

Following completion of the multi-game prototype (it also offered table tennis) in mid-1967, demonstrations were conducted by Sanders Associates for possible licensees. After a deal with RCA fell through, talks were held with Magnavox and, in May, 1972, Odyssey was announced. The first version of Odyssey was manufactured until 1975 when it was replaced by an improved model which employed LSI parts.

The United States patent application for the video paddle game was filed on March 24, 1975 by Baer and the patent (number 3,993,861) was granted on November 23, 1976. □

Design a Video Game — Make a Million Dollars

"I showed them how the game was played, and, within a few minutes, I knew they were going to buy it."
— Ed Averett, Game Cartridge Designer

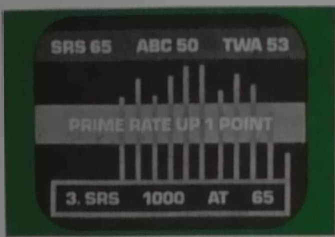
Ed and Linda Averett first met in a calculus class at the University of Tennessee while Ed was pursuing BSEE and MSEE degrees and Linda was earning a degree in engineering physics. They graduated, married and Linda followed Ed to New Jersey when the Army assigned him to Fort Monmouth. While Ed soldiered, Linda, working nearby for a computer company, was introduced to software development.

"By the time my military stint was up," recalls Ed, "Linda had learned enough about computers to receive a job offer from Hewlett-Packard in Palo Alto. So we packed up and headed for California." A short time later, Ed accepted an employment offer from Intel Corp. in Santa Clara.

His role as a marketing engineer for consumer products at Intel brought Ed into contact with Mike Staup, vice president of product development for Odyssey. Intel was the supplier of the 8048 microprocessor and the 8244 graphics chip, both used by Magnavox in the design of the Odyssey 2 video-game-system console.

Couldn't Refuse Offer

Ed suspected that he knew more about the capabilities of the 8048 to control game action than his customer's engineers and he approached Staup with a proposition. "I told Mike I would resign my position at Intel and design a video-game cartridge if he would agree to review it for possible use by Magnavox on a royalty basis," Ed relates.



Odyssey's Wall Street Game

"How could I refuse," Staup points out. "It didn't cost me anything."

On April 1, 1977, at the age of 28, Ed left Intel and raised $20,000 (most of the money came from exercising his Intel stock options) to buy an MDS-800 microprocessor development system from his former employer. To make room for the system, the Averetts moved their living room furniture to other parts of the house.

Linda, who, by this time had advanced to software systems manager at Hewlett-Packard, continued to work. Ed's daytime hours were spent exploring video game possibilities and caring for the couple's 18-month-old daughter. After the dinner dishes were cleared each evening, Linda joined the effort. "She was the software heavy," say Ed.

Three months later the completed game design, stored on a floppy disk, was ready for demonstration. Ed packed his suitcase and headed for Magnavox.

"I showed them how the game was played and, within a few minutes, I knew they were going to buy it," recalls Ed. He was right.

The game employed robots that would chase or be chased through a maze. Runing after or escaping a robot sometimes involved stooping to fit through tight passageways. The ability to catch or avoid robots affected the player's income, displayed continuously at the bottom of the screen. The game was called "Take the Money and Run."

Ed, too, was off and running. More games soon followed. By the time "The Great Wall Street Fortune Hunt" was announced in April, 1982, Averett had designed 20 Odyssey cartridges and more are on the drawing board.

The Averetts are back in Chattanooga where Ed continues to do his design work in a computer lab in his home. Linda is still involved, at least as a sounding board. Although only 90 minutes by car from Odyssey headquarters in Knoxville, Ed's contact with the game company is mainly by telephone. Completed games are assigned to Sam Overton, Odyssey's software development manager. Promotion and package design is entrusted to Steve Lehner, an ex-advertising executive employed as a creative consultant.

According to an Odyssey spokesman, Averett earned more than $1.5 million in royalties during 1981 and is probably making about $2 million annually at the present time.

Can someone else follow in Ed Averett's footsteps? "Sure," says Staup. "If a designer contacts us and we're convinced that he has the background to really code well, we'll look at his work."

Hybrids and monolithics: from competition to peaceful coexistence

"As the technologies evolve and mature, the market window will continue to slide upward, with monolithics taking sockets from hybrids at one end and hybrids taking sockets from discrete modules at the other end."
— Stephen Forrester, Datel-Intersil

Because of the similarities in hybrid and monolithic technologies, and their somewhat overlapping development, there has been a good deal of controversy as to their respective positions in the marketplace. Actually, hybrid and monolithic components should rarely compete head to head. Normally, this happens when a new monolithic design is aimed at the sockets of an older hybrid device, such as the original DG181 family of analog switches (several discrete FET chips and a bipolar driver) and their more recent CMOS monolithic pin-for-pin counterparts.

Hybrid technology exists between monolithic and discrete modular technology, combining and sharing in the positive attributes of both. It shares with discrete designs the advantages of selecting optimum components from a wide variety of IC processing technologies to reach overall performance levels denied to monolithics. At the same time, hybrids achieve a significant price advantage over discrete modules through much higher production efficiencies. Hybrids can offer significant performance advantages over monolithic designs despite greater real estate requirements and higher cost.

A Significant Advantage

An extremely important advantage of the hybrid design approach is its ability to combine optimum circuit components in a single package. For example, a typical hybrid analog-to-digital converter will include a high-speed comparator, ultra-fast current switches, a successive approximation register, a low-drift voltage reference, highly stable thin-film resistor networks and various discrete components. A mixture of technologies as diverse as CMOS, Schottky diode and thin-film resistors is not unusual. Monolithic circuits are now available that use one or more of the following process technologies: CMOS, bipolar, I^2L, TTL and thin-film deposition. Recent developments have allowed the combination of two or more technologies in a monolithic integrated circuit, but serious difficulties arise when the IC manufacturer attempts to combine linear and digital circuitry with precision, high-stability resistor networks.

Obviously, the ability to select components from any of the IC processing families gives hybrids a design advantage over monolithics. Some other hybrid advantages are not so obvious. Hybrid components are essentially monolithic and discrete devices mounted on a common substrate and interconnected with wire bonds and a circuit pattern laid out on the substrate. Since monolithic chips are an essential part of any hybrid component, the hybrid designer is able to take advantage of most advances in monolithic technology.

As more complex monolithic ICs become available, the hybrid manufacturer can reduce chip count per device to accomplish more complex functions per package. As devices such as the new monolithic DAC-80s become available, hybrid designers may use the real estate saved by the on-chip reference and output operational amplifier to add more peripheral functions. These added functions could take the form of digital selection circuitry for an instrumentation amplifier (AM-542/543), systems interface circuitry (DAC-HK12B), or even a miniature thick-film screened transformer for an isolation amplifier (AD 293/294).

Military and aerospace programs require high reliability devices subjected to rigorous screening procedures. For a number of years, hybrid manufacturers have encountered serious difficulties in their attempts to supply products screened to the applicable military standards.

Many difficulties have ensued because MIL-M-38510 was written specifically as a military procurement document for single-chip monolithic ICs and is semiconductor-process orientated. Because of the inherent complexity of multi-chip hybrid devices, attemps to supply hybrid circuits in compliance with MIL-M-38510 were marginal at best. Also, MIL-STD-976, the military standard certification requirements for microcircuits and production facilities, is not applicable to hybrid circuits or manufacturing facilities. MIL-STD-976 is written specifically for JAN semiconductor integrated circuits. As a consequence, no hybrid circuit manufacturer has ever been able to attain facility certification or qualify a hybrid microcircuit for listing on a military qualified parts list.

Because of the increasing importance of hybrid technology to the military electronics market, much effort has been expended in the last two years to address the problem of military grade hybrid procurement. Most of this work has been accomplished by RADC (Rome Air Development Center), JEDEC (Joint Electronics Device Engineering Council), the Aerospace Corporation under government contract, and NASA (National Aeronautics and Space Administration).

New Hybrid Mil Specs

As a result of these efforts, new standards were issued on December 1, 1981. MIL-M-38510 was issued to include Appendix G. MIL-STD-1772 was generated. And significant changes, specifically concerning hybrid circuits, were made to MIL-STD-883B. MIL-M-38510E, Appendix G covers requirements for the procurement of military hybrid circuits; MIL-STD-1772 contains the requirements for certifying manufacturing facilities which supply military hybrid circuits; and MIL-STD-883B contains the standard test methods and procedures for microcircuits.

There now exists complete procurement specifications, facility capability requirements and test and screening procedures for suppliers of military hybrids. Any

Two High-Performance Amplifiers

For example, the hybrid sample-hold amplifier in Fig. 1 contains an internal precision 1000 pF hold capacitor, internal logic to facilitate dual-line sample mode control, an internal inverter to allow the use of either a positive or negative sample-mode control signal, and thin-film resistor networks that are factory-trimmed to minimize offset and sample-to-hold offset errors. The monolithic sample-hold amplifier, although lower in cost and smaller in size, requires the user to select and implement such critical external circuit components as the hold capacitor (which affects virtually all the important performance parameters of the sample-hold) and trim-circuits (which will have a direct impact on the accuracy and stability of the sample-hold).

It is even possible to implement a complete 12-bit data acquisition subsystem, capable of throughput rates of 50 kHz, in hybrid form. The HDAS-16 (see Fig. 2) contains a 16-channel analog multiplexer, programmable gain instrumentation amplifier, sample-hold amplifier, precision 1000 pF hold capacitor, 12-bit analog-to-digital converter, three-state outputs, precision reference, MUX address register, and control logic, all in a single 62 pin package. Indicative of the ruggedness inherent in hybrid fabrication, this device is available fully screened to MIL-STD-883B for operation over the full military operating temperature range of −55°C to +125°C.

A Monolithic Winner

Not all circuit designs are more easily implemented, used, or improved by using hybrid techniques. Note the recent introduction of a number of high-speed monolithic flash or parallel analog-to-digital converters. Flash converters use a number (2^N-1) of comparators in parallel, instead of one (as in the successive approximation method). The analog input is distributed simultaneously along the comparators, making for a nearly instantaneous conversion. A monolithic 9-bit device, TDC-1019J, is available and contains 511 comparators on a single 280 x 280 mil chip with a 7 MHz conversion rate. The number of comparators required . . . 63 for a 6-bit converter . . . make this type of device impractical to build in hybrid form for resolutions over 4-bits because of physical constraints, considerable cost and excessive power consumption.

But hybrid manufacturers can use these chips to build high-speed converters with higher resolutions and more functions (such as an input sample-hold). The MN5245 contains two 6-bit flash converters connected in a bit recycling circuit to produce 12 bits with a 900 nsec conversion time.

The very heart of any data converter is its resistor network. Given the excellent performance of thin-film resistors over a full temperature gradient, hybrid microcircuits routinely achieve a thermal performance far superior to monolithics. Because the hybrid designer is not as limited by size and trimming constraints, much higher accuracies and absolute values are also achievable.

A Challenge to Single Chips

In striving to match the performance of high-resolution hybrid converters, monolithic manufacturers face the challenge of making a stable bit-summing resistor network. As the converter resolution is raised, the typical R/2R ladder network be-

manufacturer who wishes to participate in the military market will be required to conform 100% to these regulations.

Some of the more significant implications of the new standards are: 1) All custom hybrid microcircuits must be manufactured, assembled, and tested within the U.S. and its territories. 2) All suppliers of military hybrids will have to receive written facility certification to MIL-STD-1772 by the government or a government authorized industry certification group This formally written and periodically audited certification will be required of all manufacturers who hope to bid on military grade hybrid contracts. 3) Screening to Method 5008 of MIL-STD-883B has been tightened and expanded for Class B circuits, and a new Class S has been added. Class S includes expanded screening requirements and increased emphasis on traceability and documentation. 4) Workmanship, rework, and repair criteria have been clearly defined, with major changes being made in each of these areas. The net effect of these changes will be to raise overall yields for military-grade hybrid microcircuits. 5) Definitive standards for a comprehensive quality assurance plan have been established, including requirements for quality conformance inspection, screening, burn-in and PDA (percent defective allowable).

The implications posed to the hybrid microcircuit specifications are clear. Comply and receive factory certification or do not participate in the high rel military market.

comes proportionately larger, occupying increasingly greater amounts of chip space. Not only does a large chip lower the chip-per-wafer yield, but it will require some type of trimming, frequently raising costs to a level too high for mass production.

To overcome these difficulties, most manufacturers of higher-resolution monolithic converters are resorting to some sort of current-weighting, error-correction, or error-averaging scheme to reduce the size of the bit-summing resistor network.

As an example, the ICL7134 uses a PROM-based correction circuit to give an accuracy of ±½ LSB at 4 bits of resolution. The PROM contains 31 correction codes, one of which is selected for each combination of the most significant five input bits of the primary DAC. The accuracy of the initial DAC can be as low as 9-bits, attainable at present levels of technology.

However, the hybrid advantage extends beyond product performance. Hybrid designs typically require only 20% of the manufacturing time and 10% to 20% of the design development costs of new monolithic designs. Prototypes of a custom hybrid device can typically be turned out in 8 to 16 weeks. Nonrecurring engineering costs are modest, running anywhere from $500 to $20,000, and production quantities as low as 500 to 1000 units can make economic sense.

On the other hand, monolithic ICs require production guarantees of approximately 100K units to be economically feasible. Noncurring engi-

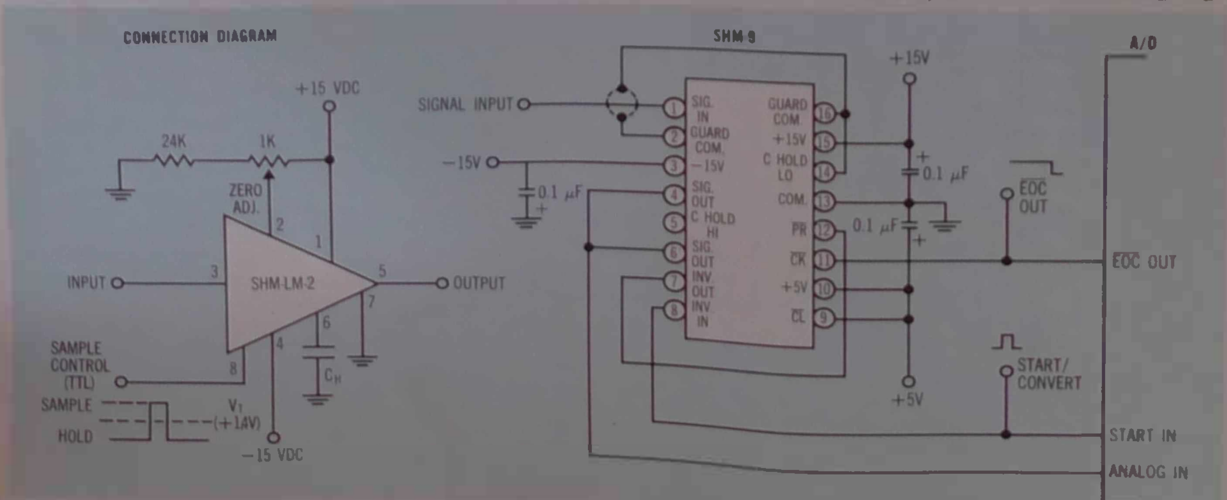


Fig. 1. Hybrid manufacturers typically offer a more complete circuit than their monolithic counterpart. The SHM-LM-2, a popular monolithic sample-hold requires the user to provide and adjust critical external components such as the hold capacitor and offset trim circuits. On the other hand, the SHM-9 a hybrid sample-hold, contains an internal hold capacitor, factory trimmed resistor networks, and internal logic circuitry to ease A/D interfacing.

neering costs can run as high as $50,000 and the design development cycle lasts several months to over a year. Also, a monolithic design is frozen early in the design cycle, with last-minute changes difficult if not impossible to make. Hybrid designs have a high degree of flexibility throughout their development cycle.

Quo Vadis?

The total data converter market now stands at approximately $230 million for the two technologies combined. Hybrid converters contribute roughly $100 million. Market expansion is healthy for both technologies, with growth rates estimated at over 30% and 40% for hybrids and monolithics, respectively.

As the technologies evolve and mature, the market window will continue to slide upward, with monolithics taking sockets from hybrids at one end and hybrids taking sockets from discrete modules at the other end. □

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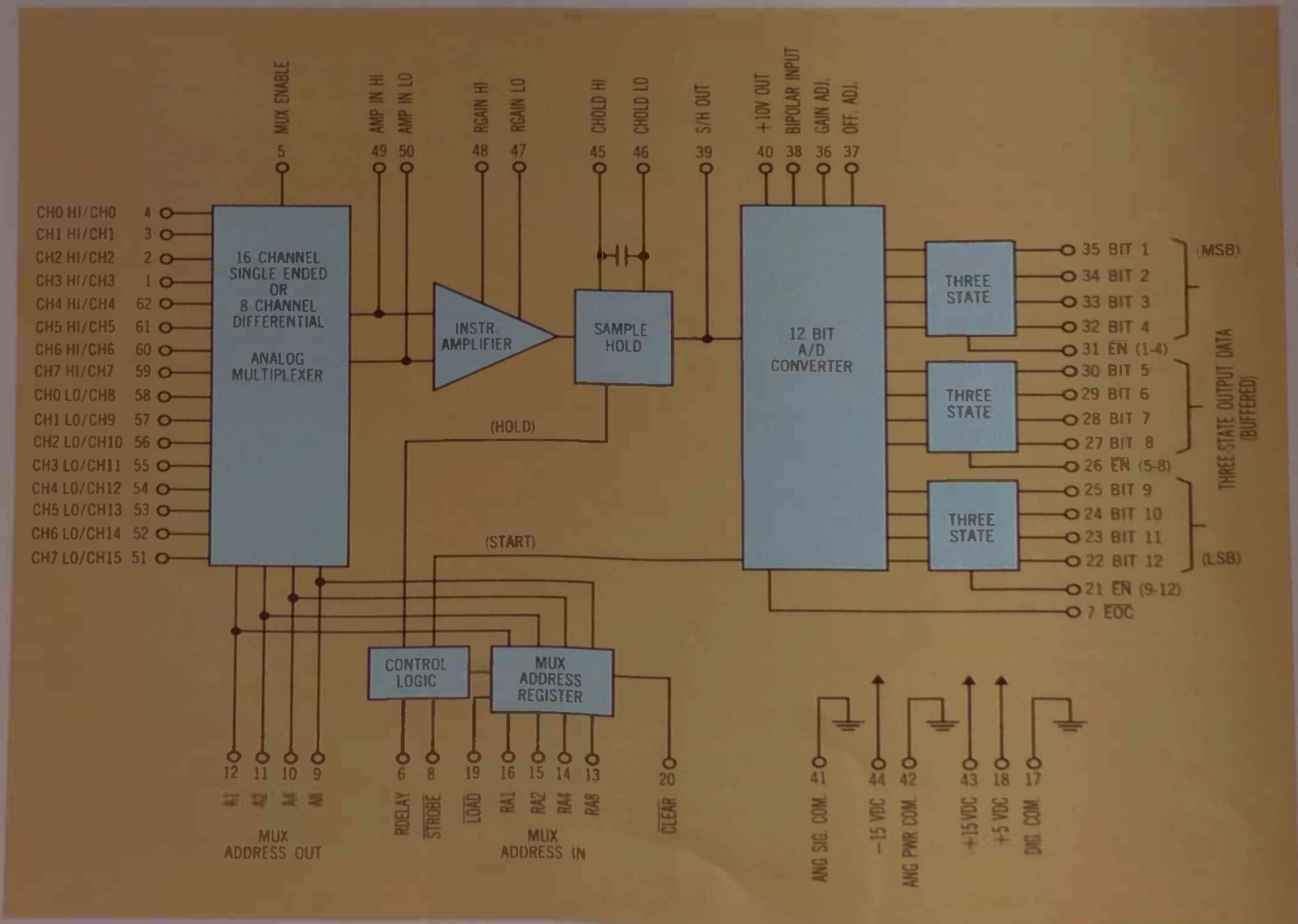

Fig. 2. The HDAS-16 contains a complete, 16-channel 12-bit data acquisition subsystem, capable of throughput rates of up to 50 kHz, in one 62 pin package. This represents a level of performance and circuit complexity unachievable using single-chip monolithic techniques.